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THE USE OF ENERGY VALUES IN THE COMPUTATION OF RATIONS FOR FARM ANIMALS.[1]

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GENERAL PRINCIPLES.

COMPONENTS OF THE ANIMAL BODY.

THE MACHINERY OF THE BODY.

The essential working parts of the body contain a great variety of substances, but these may, for our present purpose, be grouped under three heads—water, ash, and protein. The bones, constituting the framework of the body; the ligaments, muscles, and tendons, which bind together and move the bones; the skin and hair, or wool, which cover and protect the body; the internal organs of circulation, respiration, digestion, excretion, and reproduction; the brain and nerves—in short, the whole mechanism of the body—can be regarded as being composed substantially of these three classes of substances.

Water.—Rarely less than half and sometimes as much as three-fourths of the weight of the live animal consists of water. The

[1] A revision of Farmers' Bulletin 346.

proportion of water is greatest in young and lean animals and decreases as they become more mature or fatter.

Ash.—The ash or mineral matter is the portion left after complete burning. Its presence is most familiar in the bones, but it is found in all parts of the body and is just as essential as water or protein. It amounts to from 2 to 5 per cent of the weight of the body.

Protein.—Protein is the name given to a highly important group of substances, of which the white of egg, washed lean meat, the casein of milk, the gluten of wheat flour, etc., are familiar examples. They are composed of the chemical elements carbon, hydrogen, oxygen, nitrogen, and sulphur. They are what are commonly called "organic" substances, which simply means that they may be burned completely in air or oxygen. They differ from the other groups of substances found in the animal body in containing sulphur, and especially nitrogen, the latter element constituting from 15 to 18 or 19 per cent of their weight.

Protein is the basis of the living tissues of the body—the so-called protoplasm—and is the substance through which life especially manifests itself. In the body it is always associated with water and ash.

THE RESERVE MATERIAL OF THE BODY

Fat.—Besides its working parts, the body contains a store of reserve material in the form of fat. While the fat deposits in the body are of use mechanically as cushions between the various organs and as a protecting layer under the skin, nevertheless fat represents essentially a storage of material derived from feed consumed in excess of the body's immediate needs. When the feed is insufficient or entirely lacking, this store of surplus material is drawn upon, and the animal gradually becomes lean. The percentage of fat in the bodies of agricultural animals may vary greatly but seldom falls below 6 or rises above 30 per cent.

Glycogen.—Besides fat there are stored up in the muscles, liver, and other organs of a healthy animal rather small amounts of a substance called "glycogen," belonging to the group of carbohydrates described in the next section. Neither fat nor glycogen contains the elements nitrogen or sulphur, but each is composed entirely of carbon, hydrogen, and oxygen.

COMPOSITION OF THE ENTIRE BODY.

The average results of analyses shown in the following table indicate the composition of the bodies of different animals in different conditions:

Percentage composition of live animals.

	Ox.			Fat calf.	Sheep.					Swine.	
	Well fed.	Half fat.	Fat.		Lean.	Well fed.	Half fat.	Fat.	Very fat.	Well fed.	Fat.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Water	54.3	50.2	43.6	60.1	56.6	53.7	50.7	44.8	39.0	53.9	42.0
Ash	4.8	4.4	3.9	4.5	3.4	3.3	3.2	2.9	2.8	2.7	1.8
Fat	7.1	14.9	26.8	13.1	8.6	13.2	18.3	28.1	37.2	22.5	40.2
Protein	15.8	15.5	13.7	15.3	15.4	14.8	13.8	12.2	11.0	13.9	11.0
Contents of stomach and intestines	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

COMPONENTS OF FEEDING STUFFS.

Like the animal body, the vegetable feeding stuffs which nourish it contain a great variety of substances, but these, too, like those of the animal, may be classified into a few groups. Not only so, but these main groups are the same as those found in the animal, viz, water, ash, protein, fats, and carbohydrates. The proportions of these ingredients in the animal body and in vegetable substances, however, are widely different.

PROTEIN AND FAT.

Protein is the predominant ingredient, aside from water, in the animal body, while the latter stores up its reserve material in the form of fat, with but little carbohydrates (glycogen). Protein is also contained in all plants and, as in the animal, forms the basis of the living tissues, but the predominant ingredients as regards quantity are the carbohydrates. In the form of cellulose, or "crude fiber," they form the cell walls of the plant, while as starch and sugar they are stored up in large amounts in the cells of seeds and roots as reserve material. A few plants, like flax and cotton, store up oil instead of starch and are likewise rich in protein, but, as a rule, the common feeding stuffs contain relatively small amounts of protein and fat and are rich in carbohydrates.

The protein and fats of plants are not widely different from those of animals and call for no special description here.

CARBOHYDRATES.

The carbohydrates, as starch, sugar, etc., constitute a distinct group, represented in the animal chiefly by the small amounts of glycogen mentioned on page 2 and by the sugar of the milk. They are composed of the chemical elements carbon, hydrogen, and oxygen, the two latter being present in exactly the same relative amounts as

in water. Like the fats, they contain no nitrogen or sulphur, but they differ from the fats in containing less carbon and more oxygen.

The carbohydrates of feeding stuffs may be divided into two classes. The first of these includes those substances which are found in the cell walls and constitute the framework of the plant. This class includes cellulose and a great variety of other substances, most of which are rather difficult to dissolve. The "crude fiber" obtained in the analysis of feeding stuffs represents this class of carbohydrates.

The second class of carbohydrates consists of the reserve material stored up in the cells and includes starch, the various kinds of sugar, and other less familiar substances. Some of these carbohydrates, like the sugars, dissolve in water and all may be converted into soluble forms rather easily. In analyses of feeding stuffs they are contained in the "nitrogen-free extract" which, however, also includes a variety of other substances of ill-defined nature.

THE ANIMAL BODY AS A MACHINE.

Mechanically the body of an animal is a very wonderful machine, but what is of peculiar interest in this connection is that the body is what the engineer calls a prime motor—that is, like the steam or gasoline engine, it moves itself and may supply power to move other machines. In fact, there is in some respects a very close likeness between the animal body and what are known as internal-combustion motors, i. e., those engines in which power is developed by burning liquid or gaseous fuel (gasoline, alcohol, producer gas, etc.) in the cylinder of the engine itself. Such an engine requires two things for its operation: (1) Sufficient repair material to keep its working parts in running order, and (2) a supply of fuel in proportion to the work to be done. Just these same two things are what the animal requires—repair material and fuel.

In one respect, however, the animal body differs from the artificial machine—it can not be stopped and started again at will. As long as the animal lives the vital machinery is in operation, although less actively at some times than at others. The animal might be compared to an automobile whose engine must be kept running at a low speed in order to have the power available when needed. Consequently, the animal requires to be supplied with repair material and with fuel as long as it lives and not merely when it is in active use.

That the feed of the animal is its source of both repair material and fuel is sufficiently obvious. We do not need a physiologist to tell us that when an animal is deprived of feed its tissues waste away while its fat is burned up in the effort to keep the bodily machinery in motion. We may proceed at once, therefore, to consider the feed in these two relations.

THE DEMAND FOR REPAIR MATERIAL.

The repair material for any machine must be of the same kind of which the machine is made. We have just seen that the machinery of the body is composed of protein, ash, and water. These, then, are the materials which must be supplied to keep it in repair.

Water, of course, is or should be abundantly supplied in the drink and scarcely need be considered in a discussion of rations.

Ash.—The ash supply has received less attention in the past than its importance deserves. In the ordinary operation of the bodily machinery its ash ingredients are being continually excreted and the feed must supply ash sufficient in amount and of the right kinds to make good the loss, while the growing animal needs an additional supply for building up its new tissues. Fortunately, normally constituted rations appear rarely to be deficient in ash. Usually it is only when large amounts of certain by-product feeds are used or when there is a misrelation between grain and coarse fodder that special attention needs to be given to the ash supply.

Protein.—The protein supply, on the other hand, calls for careful consideration. Protein is the characteristic ingredient of the animal mechanism and is broken down and destroyed in its operation at a fairly regular rate. Moreover, since the bodily machinery is running all the time, whether any external work is done or not, this loss is continually going on.

The body differs from a machine in being self-repairing, but it can not manufacture protein for repair purposes out of the carbohydrates and fats of its feed any more than it is possible to make repairs for an automobile out of the gasoline which supplies the power. For its protein the body is absolutely dependent on the protein of the feed. This protein is needed for two purposes.

First. It is required for repair purposes in the strict sense; i. e., for making good the wear and tear of the bodily machinery. The amount needed for this purpose is comparatively small, and is no greater under normal conditions when the animal is doing work than when it is not. Like a good engine, the body makes relatively small demands for repair material and requires chiefly fuel.

Second. Protein as well as ash is needed in the growing, pregnant, or milking animal to furnish the material for enlarging the working machinery of the body of the animal itself or of its young. The amount of protein required for this purpose is just so much in addition to that needed for repair purposes simply, and hence the feed of these animals must contain a more liberal supply of this ingredient. This is important physiologically to secure proper nutrition of the young and economically because the growth or milk produced is the principal object of the feeder.

FEED AS A SOURCE OF REPAIR MATERIAL.

For the reasons stated on page 5, the ash has generally been omitted from consideration in discussing the feed as a source of repair material.

The value of a feeding stuff as a source of protein to the animal body depends in the first place on the amount of protein which it contains. Cottonseed meal, carrying some 43 per cent of protein, is evidently, other things being equal, a better source of protein than Indian corn, carrying about 10 per cent.

In the second place, however, the protein of the feeding stuff must be capable of being digested by the animal. Of two feeding stuffs containing equal amounts of protein, that one is the more valuable as a source of supply in which the larger proportion of the protein is digestible. The second and third columns of the table on pages 11–13 show the average percentages of digestible "crude" and "true" protein contained in a number of the more common feeding stuffs. These figures are the average results of a considerable number of analyses of the feeding stuffs and a smaller number of determinations of their digestibility. Individual samples may vary more or less, and sometimes considerably, from the average.

A third question is at once suggested, viz, whether the digestible protein from different feeding stuffs is equally valuable to the animal. Recent investigations have shown that this is not the case. Single proteins have been found to vary widely in nutritive value, and in particular the mixed proteins of the cereals appear to be of somewhat inferior quality. In ordinary mixed rations, however, it appears doubtful whether these differences are of very much practical significance. At any rate, pending further investigation, the only course which seems open at present is to assume the proteins of the various feeding stuffs to be of substantially equal value.

THE DEMAND FOR FUEL MATERIAL.

Since the animal machinery is running continually, it requires a continual supply of fuel material, the amount which is necessary depending upon the amount of work done. This fuel material consists chiefly of the carbohydrates and fats of the feed, although if more protein be fed than is required for repair and construction purposes it, too, may be used as fuel, while the worn-out portions of the protein tissues are also utilized—that is, the bodily engine can burn up its own waste products as fuel. The unnecessary use of protein as fuel material, however, is wasteful, because protein is ordinarily more expensive to buy or to produce on the farm than are carbohydrates and fats.

If the fuel materials supplied in the feed are just adequate to the work to be done, they are virtually burned up as a source of power. If more are supplied than are immediately needed, the body is able to store away the surplus for future use, much as we may fill up the gasoline tank of an engine. To a small extent the body stores up carbohydrates (in the form of glycogen), but most of its surplus fuel it converts into fat. The fat of the body, therefore, is its reserve of fuel. In fattening, the body is accumulating a surplus against future needs which man diverts to his own use as food. If the feed becomes insufficient, this store is drawn upon and the animal gradually becomes lean. Similarly, in growth and in milk production, the animal sets aside a part of the supply of both repair and fuel material in its feed for its own growth or for the use of its young, and man appropriates the resulting meat or milk as repair and fuel material for his own body.

FEED AS A SOURCE OF FUEL MATERIAL.

We can run an engine with various kinds of fuel. For the steam engine we may use coal or wood or petroleum; for the internal-combustion motor, gas, alcohol, or gasoline may be employed. Similarly, we supply the animal body with a great variety of feeding stuffs from which it has to extract its supply of fuel, and even the materials which it actually burns up are of various sorts.

These fuel materials are not all of equal value. A pound of good anthracite coal, for example, is, other things being equal, about 14 per cent more valuable as fuel than the same weight of alcohol, while a pound of fat in the feed has over twice the fuel value of a pound of starch. Evidently, it will greatly simplify comparisons of different feeding stuffs and rations as sources of fuel material to have some simple method by which we can learn not only the amount of fuel material which the feed contains, but also the quality of that fuel. Such a basis of comparison is afforded by a study of the energy values.

MEASUREMENT OF ENERGY.

Anything which has the capacity to do work is said to possess energy. Hence we say that the fuel of the engine and the feed of the animal possess energy, since they enable the engine or the body to do work. They hold this energy stored up in the "latent" or "potential" form of chemical energy. When they are burned in the engine or the body, this chemical energy is set free, part of it being converted into work and the rest escaping as heat.

Plainly, then, the value of a fuel, or of a feeding stuff so far as it serves as fuel, depends, in the first place, on how much chemical energy it contains. This can be measured without difficulty by con-

verting it all into heat, by burning the substance, and measuring the heat produced. Various units have been employed in measuring heat, but the one used in this bulletin is the therm.

A therm[1] is the quantity of heat required to raise the temperature of 1,000 kilograms (2,204.6 pounds) of water 1° C. A pound of good anthracite coal would produce heat enough to raise the temperature of about 3,583 kilograms of water 1° C. Consequently, the chemical energy contained in the coal is 3.583 therms per pound. In precisely the same way the amount of chemical energy contained in many feeding stuffs has been measured. The following are the results of a few such determinations:

Chemical energy in 100 pounds.[2]

	Therms.
Timothy hay	175.1
Clover hay	173.2
Oat straw	171.0
Wheat straw	171.4
Corn meal	170.9
Oats	180.6
Wheat bran	175.5
Linseed meal	196.7

UTILIZATION OF ENERGY.

But the value of a fuel depends also upon how much of the chemical energy which it contains can be used. Hard coal contains plenty of energy, but it would not be of much use to run a gasoline engine. Wheat straw contains fully as much chemical energy as corn meal, but much of that energy can not be utilized by the animal machine.

Two causes combine to affect the utilization of the chemical energy contained in feeding stuffs.

First, more or less of the feed escapes from the body unburned. If a coal is of such quality that portions of it drop through the grate unconsumed, and if smoke and combustible gases are carried off through the stack, it is evident that a ton of it will supply far less heat to the boiler than it would if the combustion were perfect. The case of the feeding stuff is similar. Much of even the best feeding stuffs escapes digestion and is excreted in the dung, carrying with it a corresponding quantity of the chemical energy of the feed. More

[1] In the nutrition investigations and studies of foods and feeding stuffs made by this department and by the State agricultural experiment stations, the results, so far as energy or fuel value is concerned, have been expressed in calories, the unit so used being the large or kilogram calorie, as distinguished from the small or gram calorie. There is consequently a large mass of available data so expressed. The calorie thus used is the amount of heat required to raise 1 kilogram of water 1° C. (approximately 1 pound of water 4° F.). The small size of the unit has made it necessary to use inconveniently large numbers to express the fuel values of foods and feeding stuffs, a difficulty which is obviated by the use of the therm. As the latter unit is equivalent to 1,000 large calories, available data, such, for example, as those in Farmers' Bulletin 22, can be readily given expression in the new unit. The use of the word therm, with the abbreviation *t.*, has also been proposed as the equivalent of the small (or gram) calorie, but it has not come into general use.

[2] With 15 per cent moisture.

or less incompletely burned material is also contained in the urine, while ruminants, and to a certain extent horses and swine, also give off combustible gases arising from fermentations in the digestive tract. Thus about 22 per cent of the chemical energy of corn meal and fully 55 per cent of that of average hay has been found to escape in these ways.

Second, as already pointed out, the animal body has to extract its real fuel material from its feed, separating it from the relatively large proportion of useless material which it excretes. To effect this separation requires work and consumes energy, and this energy, of course, is not available for other purposes. The case is somewhat as if the gasoline engine had to distill its own gasoline and separate it from impurities. Moreover, it appears to be well established that the digestible substances taken up from the alimentary tract act as a direct stimulus to the combustions going on in the body; that is, that the body may burn up more material simply because a larger supply is available, while there is some evidence that an increase in the feed consumed tends to stimulate the minor incidental movements of the animal, or, in other words, to render the animal more restless, especially when standing.

It is not, then, the total chemical energy contained in a feeding stuff which measures its value as fuel material to the body, but what remains after deducting the losses in the unburned materials of the excreta and the energy expenditure incident to the consumption of the feed. This remainder is called its net energy.

For example, while 100 pounds of corn meal contain, as stated, about 170.9 therms of chemical energy, only about 88.8 therms remain, after all these deductions have been made, to represent the actual value of the corn meal as a source of energy to the organism.

NET ENERGY VALUES OF FEEDING STUFFS.

While it is a comparatively simple matter to ascertain the total amount of chemical energy contained in a feeding stuff, the determination of the proportion of this energy which the body can actually utilize, i. e., its net energy value, requires the use of complicated and costly apparatus (respiration apparatus or respiration calorimeter) and the expenditure of much time and labor. While much has been accomplished along this line, vastly more still remains to be done before we can claim to have a complete knowledge of the energy values of feeding stuffs. At the same time, enough has already been accomplished, through the investigations of G. Kühn and of Kellner at the Möckern Experiment Station in Germany, since 1882, and by the experiments carried on, in cooperation with this Department, by the Institute of Animal Nutrition of The Pennsylvania State College, to demonstrate that the method still generally current of

comparing feeding stuffs on the basis of the digestible matter which they contain is seriously erroneous and to permit the computation of at least tentative net energy values. A summary of the results of these investigations has been published in Bulletin 142 of the Pennsylvania Experiment Station together with an outline of the methods used for computing the net energy values of feeding stuffs which have not been the subject of direct experiment.

Henry and Morrison[1] have recently published a very valuable compilation of American analyses of feeding stuffs and of the results of American digestion experiments, and on this basis have calculated the content of digestible nutrients (for ruminants) in a great variety of feeding stuffs.

With the permission of these authors, the writer, in cooperation with Prof. F. S. Putney, of The Pennsylvania State College, has computed from their tables the net energy values of the more important feeding stuffs with the results contained in the following table, which includes the digestible (true) protein and also the nonprotein estimated on the basis of Kellner's averages. In regard to this table it is to be remarked—

First. Both the digestion coefficients used by Henry and Morrison and the data for the expenditure of energy due to feed consumption are derived exclusively from experiments on ruminants (cattle). Consequently, the net energy values here computed are directly applicable to ruminants only.

Second. The table shows primarily the net energy values for maintenance or fattening. There seems good reason for believing, however, that they may be taken without serious error to represent also the net energy values for growth and at least the relative values for milk production. Kellner believes that the same net energy values may also be regarded as expressing with sufficient accuracy the relative values of feeding stuffs for horses and for swine. The requirements for these animals, therefore, as tabulated on the following pages, are substantially those given by Kellner.

[1] Feeds and Feeding, 15th edition, pp. 638–666.

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
DRIED ROUGHAGE.				
Hay and fodder from cereals.	*Pounds.*	*Pounds.*	*Pounds.*	*Therms.*
Brome grass, smooth	91.5	5.0	3.5	40.83
Corn fodder (ears included, medium dry)	81.7	3.0	2.3	43.94
Corn stover (ears removed, medium dry)	81.0	2.1	1.6	31.62
Millet, Hungarian	85.7	5.0	3.9	46.96
Mixed timothy and clover	87.8	5.3	3.2	41.07
Oat hay	88.0	4.5	3.9	32.25
Orchard grass	88.4	4.7	3.3	44.93
Redtop	90.2	4.6	3.9	51.22
Timothy, all analyses	88.4	3.0	2.2	43.02
Timothy, before bloom	92.8	4.7	2.9	43.52
Timothy, early to full bloom	87.2	3.6	2.5	47.40
Timothy, late bloom to early seed	85.1	2.4	1.8	37.54
Timothy, nearly ripe	87.5	2.2	1.8	38.59
Hay and fodder from legumes.				
Alfalfa, all analyses	91.4	10.6	7.1	34.23
Alfalfa, before bloom	93.8	15.4	10.3	36.23
Alfalfa, in bloom	92.5	10.5	6.7	32.33
Alfalfa, in seed	89.6	8.5	6.2	32.23
Clover, alsike	87.7	7.9	5.3	34.42
Clover, crimson	89.4	9.7	6.9	36.21
Clover, red, all analyses	87.1	7.6	4.9	38.68
Clover, red, before bloom	89.6	11.6	5.4	42.17
Clover, red, in bloom	86.1	8.1	5.3	39.12
Clover, red, after bloom	77.9	6.8	4.5	34.51
Clover, sweet white	91.4	10.9	6.7	38.98
Cowpeas, all analyses	90.3	13.1	9.2	37.59
Cowpeas, before bloom	92.2	17.8	12.8	33.54
Cowpeas, in bloom to early pod	89.4	12.6	9.5	39.11
Soy beans	91.4	11.7	8.8	44.03
Straws.				
Barley	85.8	.9	.6	36.61
Buckwheat	90.1	4.2	3.2	4.55
Oat	88.5	1.0	.8	34.81
Rye	92.9	.7	.5	17.59
Wheat	91.6	.7	.3	7.22
FRESH GREEN ROUGHAGE.				
Green cereals, etc.				
Barley fodder	23.2	2.3	2.0	14.08
Bluegrass, Kentucky, before heading	23.8	3.7	2.8	14.82
Bluegrass, Kentucky, headed out	36.4	2.8	2.2	17.77
Bluegrass, Kentucky, after bloom	43.6	1.9	1.6	21.01
Buckwheat, Japanese	36.6	2.2	1.5	17.78
Cabbage	8.9	1.9	1.3	8.87
Cabbage, waste outer leaves	14.1	1.7	1.1	7.05
Corn fodder, dent, all analyses	23.1	1.0	.8	14.60
Corn fodder, dent, in tassel	14.9	1.1	.8	9.52
Corn fodder, dent, in milk	19.9	1.0	.8	13.64
Corn fodder, dent, dough to glazing	25.1	1.3	1.0	17.35
Corn fodder, dent, kernels glazed	26.2	1.1	.8	16.74
Corn fodder, dent, kernels ripe	34.8	1.5	1.1	22.48
Corn fodder, flint, all analyses	20.7	1.0	.8	13.53
Corn fodder, flint, in tassel	10.6	.9	.7	6.89
Corn fodder, flint, in milk	15.0	.9	.7	10.39
Corn fodder, flint, kernels glazed	21.0	1.0	.8	13.49
Corn fodder, flint, kernels ripe	27.9	1.2	.9	17.84
Corn fodder, sweet, before milk stage	10.0	.8	.6	7.82
Corn fodder, sweet, roasting ears or later	20.3	1.2	.9	13.38
Corn fodder, sweet, ears removed	21.5	1.0	.8	14.26
Millet, Hungarian	27.6	1.9	1.1	17.24
Oat fodder	26.1	2.3	2.0	14.06
Orchard grass	29.2	1.7	1.1	15.81
Rape	16.7	2.6	1.7	13.07
Rye fodder	21.3	2.1	1.4	15.99
Sweet sorghum fodder	24.9	.7	.4	15.37
Timothy, before bloom	24.2	1.8	1.1	18.36
Timothy, in bloom	32.1	1.3	.8	18.89
Timothy, in seed	46.4	1.5	1.0	26.36
Wheat fodder	27.4	2.8	1.9	18.75

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants—Continued.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
FRESH GREEN ROUGHAGE—continued.				
Green legumes.	*Pounds.*	*Pounds.*	*Pounds.*	*Therms.*
Alfalfa, before bloom	19.9	3.5	1.9	9.20
Alfalfa, in bloom	25.9	3.3	1.8	11.50
Alfalfa, after bloom	29.8	2.1	1.3	11.10
Clover, alsike	24.3	2.7	1.5	14.56
Clover, crimson	17.4	2.3	1.6	10.83
Clover, red, all analyses	26.2	2.7	1.7	15.87
Clover, red, in bloom	27.5	2.7	1.8	16.74
Clover, red, rowen	34.4	3.3	2.2	17.30
Cowpeas	16.3	2.3	1.7	10.42
Peas, Canada field	16.6	2.9	2.1	9.78
Soy beans, all analyses	23.6	3.2	2.4	12.53
Soy beans, in bloom	20.8	3.0	2.3	10.44
Soy beans, in seed	24.2	3.1	2.5	12.70
Vetch, hairy	18.1	3.5	2.4	11.95
SILAGE.				
Corn, well matured, recent analyses	26.3	1.1	.6	15.90
Corn, mature	21.0	1.0	.4	11.96
Corn, from frosted ears	25.3	1.2	.6	14.27
Corn, from field-cured stover	19.6	.5	.3	8.98
Clover	27.8	1.3	.8	7.26
Cowpeas	22.0	1.8	1.1	11.05
Soy beans	27.1	2.6	1.5	11.59
Sugar-beet pulp	10.0	.8	.5	9.32
ROOTS, TUBERS, AND FRUITS.				
Apple	18.2	.4	.1	15.92
Beet, common	13.0	.9	.1	7.84
Beet, sugar	16.4	1.2	.4	11.20
Carrot	11.7	.9	.5	9.21
Mangels	9.4	.8	.1	5.68
Potatoes	21.2	1.1	.1	18.27
Pumpkin, field	8.3	1.1	.6	6.05
Rutabaga	10.9	1.0	.3	8.46
Turnip	9.5	1.0	.4	6.16
GRAINS.				
Cereal grains.				
Barley	90.7	9.0	8.3	89.94
Buckwheat	87.9	8.1	7.2	59.73
Corn, dent	89.5	7.5	7.0	89.16
Corn, flint	87.8	7.7	7.2	87.50
Corn-and-cob meal	89.6	6.1	5.7	75.80
Corn meal	88.7	6.9	6.4	88.75
Oats	90.8	9.7	8.7	67.56
Oatmeal	92.1	12.8	11.5	86.20
Rye	90.6	9.9	9.0	93.71
Wheat, all analyses	89.8	9.2	8.1	91.82
Wheat, winter	89.1	8.7	7.7	91.66
Wheat, spring	89.9	9.2	8.1	91.41
Leguminous seeds.				
Bean, navy	86.6	18.8	16.4	73.29
Cowpea	88.4	19.4	16.9	79.46
Pea, field	90.8	19.0	16.6	78.72
Pea meal	89.1	19.8	17.2	77.62
Peanut, with hull	93.5	19.4	16.9	83.15
Peanut kernel	94.0	24.1	22.2	109.04
Soy bean	90.1	30.7	27.3	81.29
Oil seeds.				
Cotton seed	90.6	13.3	11.9	78.33
Flaxseed	90.8	20.6	19.2	83.17
Sunflower seed	95.5	23.3	20.2	95.77
Sunflower seed, with hulls	93.1	13.5	11.7	92.49

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants—Continued.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
DAIRY PRODUCTS.	*Pounds.*	*Pounds.*	*Pounds.*	*Therms.*
Buttermilk	9.4	3.4	3.4	13.32
Cow's milk	13.6	3.3	3.3	29.01
Skim milk, centrifugal	9.9	3.6	3.6	14.31
Skim milk, gravity	9.6	3.1	3.1	15.43
Skim milk, dried	91.7	34.4	34.4	103.91
Whey	6.6	.8	.8	10.39
BY-PRODUCTS.				
Fermentation industries.				
Brewers' grains, dried	92.5	21.5	20.2	53.38
Brewers' grains, dried, below 25 per cent protein	91.8	18.7	17.5	50.93
Brewers' grains, wet	24.1	4.6	4.4	14.53
Distillers' grains, dried, from corn	93.4	22.4	18.3	85.08
Distillers' grains, dried, from rye	92.8	13.6	11.1	56.01
Distillers' grains, wet	22.6	3.3	2.8	22.05
Malt	94.2	15.8	11.8	87.82
Malt sprouts	92.4	20.3	12.5	72.72
Milling.				
Buckwheat bran	88.8	10.5	9.1	30.59
Buckwheat hulls	89.7	.4	(?)	−7.69
Buckwheat middlings	88.0	24.6	20.8	72.19
Hominy feed	89.9	7.0	6.5	81.31
Rye bran	88.6	12.2	10.5	79.35
Wheat bran	89.9	12.5	10.8	53.00
Wheat middlings, flour	89.3	15.7	14.0	75.02
Wheat middlings, standard	89.6	13.4	12.0	59.10
Oil extraction.				
Coconut meal, low in fat	90.4	18.8	18.3	83.49
Coconut meal, high in fat	92.3	18.4	18.0	100.31
Cottonseed hulls	90.3	.3	(?)	9.92
Cottonseed meal, choice	92.5	37.0	35.4	93.46
Cottonseed meal, prime	92.2	33.4	32.0	90.00
Germ oil meal, corn	91.1	16.5	14.3	83.88
Linseed meal, new process	90.4	31.7	30.9	85.12
Linseed meal, old process	90.9	30.2	28.5	88.91
Palm-nut cake	89.6	12.4	12.0	94.18
Peanut cake from hulled nuts	89.3	42.8	41.4	93.55
Peanut cake, hulls included	94.4	20.2	19.5	42.57
Soy-bean meal, fat extracted	88.2	38.1	37.3	99.65
Sunflower seed, cake	90.0	32.0	29.1	88.87
Starch manufacture.				
Gluten feed	91.3	21.6	20.1	80.72
Gluten meal	90.9	30.2	28.1	84.15
Starch feed, dry	90.7	11.2	9.2	77.46
Starch feed, wet	33.4	4.1	3.7	30.45
Sugar manufacture.				
Molasses, beet	74.7	1.1	.0	57.10
Molasses, cane or blackstrap	74.2	1.0	.0	55.38
Molasses, beet-pulp	92.4	5.9	3.5	76.28
Sugar-beet pulp, dried	91.8	4.6	.7	75.87
Sugar-beet pulp, ensiled	10.0	.8	.5	9.32
Sugar-beet pulp, wet	9.3	.5	.5	8.99
Packing house.				
Dried blood	90.3	69.1	68.6	68.12
Tankage:				
Over 60 per cent protein	92.6	58.7	55.6	93.04
55 to 60 per cent protein	92.5	54.0	51.1	83.58
45 to 55 per cent protein	92.5	48.1	45.5	72.96
Below 45 per cent protein	93.5	37.6	35.6	54.16

FEED REQUIREMENTS.

Assuming that the foregoing table represents with a fair degree of accuracy the amount of repair material (protein) on the one hand and of energy on the other which the various feeding stuffs can supply, we still need to know how much of each is required by the bodies of animals of different kinds and kept for different purposes; in other words, we need some formulation of the feed requirements of farm animals.

REQUIREMENTS FOR MAINTENANCE.

Since the animal machine may not be stopped when it is not in active use, it requires, as was pointed out on page 4, and as is a familiar fact of experience, a continual supply of feed. This amount of feed, which is required simply to support the animal, is commonly designated as the "maintenance requirement"—that is, it is the amount required simply to maintain the animal when it is doing no work and producing nothing. In other words, it is the least amount on which life can be permanently maintained.

The maintenance requirement is naturally greater for a large than for a small animal. Experiment has shown, however, that this increase is not proportional to the weight of the animal, but approximately to the amount of surface which it exposes, so that the large animal requires less feed in proportion to its weight to maintain it than does the small one.

The following tables show the amounts of protein and of net energy required per head for the maintenance of cattle, sheep, and horses of different weights. The figures given for sheep include a sufficient allowance for the normal growth of wool. No very satisfactory figures for swine are available. It should be understood that strict accuracy is not claimed for these figures, although they are substantially correct. In particular there seems to be reason to believe that the maintenance requirement of fattening animals increases somewhat more rapidly than these tables indicate.

Maintenance requirements of cattle and horses, per day and head.

Live weight.	Cattle.		Horses.	
	Digestible protein.	Net energy value.	Digestible protein.	Net energy value.
Pounds.	*Pounds.*	*Therms.*	*Pounds.*	*Therms.*
150	0.15	1.70	0.18	2.10
250	.20	2.40	.24	2.90
500	.30	3.80	.36	4.60
750	.40	4.95	.48	6.00
1,000	.50	6.00	.60	7.30
1,250	.60	7.00	.72	8.50
1,500	.65	7.90	.78	9.60

Maintenance requirements of sheep, per day and head.

Live Weight.	Digestible protein.	Net energy value.
Pounds.	*Pounds.*	*Therms.*
20	0.013	0.30
40	.028	.54
60	.039	.71
80	.050	.87
100	.055	1.00
120	.061	1.13
140	.072	1.25

REQUIREMENTS FOR GROWTH.

While young animals gain in weight faster than do older ones, a pound of increase in live weight in the young animal contains much more water and less dry matter than in the case of a more mature animal. Moreover, the dry matter in the case of the young animal contains relatively more protein and less fat, as a rule, than in the older one, and fat contains much more chemical energy than protein, the proportion being 1 to 1.67. The consequence is that a gain of 1 pound in live weight represents the storing up of much less energy in the young than in the mature animal, and therefore requires a smaller supply of energy in the feed.

Unfortunately no very extensive determinations of the composition and energy values of the increase of live weight in growing animals have yet been reported. The following estimates by the writer, derived from such data as are available, may serve to give a general idea of the requirements per pound of growth of cattle and sheep at different ages, but they can not lay claim to any high degree of accuracy. The figures refer to normal growth, with no considerable fattening.

Estimated energy value of 1 pound of gain in weight by growing cattle and sheep.

Age.	Net energy value.
Months.	*Therms.*
3	1.50
6	1.75
12	2.00
18	2.50
24	2.75
30	3.00

The growing animal also requires a sufficient supply of digestible protein for maintenance and to supply material for new growth. No very systematic study of the latter requirement has yet been made, but from the results of a considerable number of practical feeding trials it is possible to make a fairly satisfactory estimate of the total

amounts of digestible protein which should be contained in the rations of cattle and sheep at different ages to insure satisfactory growth. These estimates are contained in the following table. They are expressed in pounds per head and include the maintenance requirement. As a matter of convenience, the table also contains the estimated net energy values required per head for normal growth, and it thus constitutes a set of approximate feeding standards. In their use the weight rather than the age of the animal should be the controlling factor.

Estimated requirements [1] *per day and head.*

FOR GROWING CATTLE.

Age.	Beef breeds.			Dairy breeds.		
	Live weight.	Digestible protein.	Net energy value.	Live weight.	Digestible protein.	Net energy value.
Months.	*Pounds.*	*Pounds.*	*Therms.*	*Pounds.*	*Pounds.*	*Therms.*
3	200	0.80	4.2	165	0.65	3.6
6	350	1.10	5.0	275	.85	4.1
9	450	1.25	5.7	325	.90	4.4
12	550	1.40	6.5	400	1.00	5.1
18	750	1.50	8.2	550	1.10	6.4
24	900	1.60	9.3	700	1.20	7.6
30	1,000	1.60	9.9	800	1.20	8.2

FOR GROWING SHEEP.

Age.	Mutton breeds.			Wool breeds.		
	Live weight.	Digestible protein.	Net energy value.	Live weight.	Digestible protein.	Net energy value.
Months.	*Pounds.*	*Pounds.*	*Therms.*	*Pounds.*	*Pounds.*	*Therms.*
6	72	0.31	1.05	65	0.28	0.95
9	98	.27	1.20	82	.23	1.05
12	115	.24	1.35	90	.20	1.15
15	130	.24	1.50	95	.18	1.18
18	150	.23	1.65	100	.15	1.20

[1] Including the maintenance requirement.

No satisfactory data for colts are available, while, as noted on page 10, our knowledge of the relative values of feeding stuffs for swine is somewhat deficient.

REQUIREMENTS FOR FATTENING.

The foregoing data refer to what might be called normal growth, in which the animals are kept in a good thrifty condition, but do not become fat. If any considerable fattening is desirable, somewhat heavier rations must be given in proportion to the amount of gain made, because the increase gain in fattening animals consists to a very large extent of fat and therefore means the storing up by the animal of more reserve energy. For fairly mature fattening ani-

mals—such, for example, as the 2 to 3-year-old steers which are commonly fattened in the corn belt—probably 3.25 therms of net energy per pound of gain in live weight is a fair allowance, although more appears to be often used in practice. As yet no corresponding data are available for the fattening of growing animals, as, for example, in the production of the so-called baby beef. It is not probable, however, that any larger amount of protein is required in such fattening than in feeding simply for normal growth, so that the additional feed given for fattening may, from this point of view, consist largely of nonnitrogenous material; that is, carbohydrates and fats. It is to be noted, however, that an excess of these materials in the ration tends to cause less perfect digestion and also that a moderate proportion of the more nitrogenous concentrates seems to promote the consumption of heavy rations. Kellner recommends that at least 1 pound of digestible protein be supplied in the ration for each 8 to 10 pounds of carbohydrates and fat.

REQUIREMENTS FOR MILK PRODUCTION.

Of all forms of animal production that of milk is perhaps the most variable and most influenced in its amount by the feed supply. The energy relations of milk production have not been very fully investigated. Tentatively, however, it seems safe to estimate that the production of 1 pound of average milk, containing about 13 per cent of total solids and 4 per cent of fat, will require approximately 0.27 therm of net energy value in the feed. Naturally this amount would vary with the quality of the milk, milk rich in fat and in total solids requiring more than milk containing more water or a lower percentage of fat.

The matter of the protein requirements for milk production has not been altogether cleared up. It seems to have been pretty well demonstrated that, for a time at least, a moderate milk production may be kept up on a supply of protein only slightly exceeding that found in the milk produced (of course, in addition to the maintenance requirement). In the case of average milk, this would call for about 0.032 pound of digestible protein for each pound of milk. It has not been demonstrated, however, that a cow can keep this up indefinitely. Furthermore, for the production of liberal yields of milk more protein seems to be required, or at least to be advantageous.

Tentatively, the requirements of digestible true protein and of net energy for the production of 1 pound of milk may be formulated as follows.

Requirements for the production of 1 pound of milk.

Fat in milk.	Requirements.	
	Digestible protein.	Net energy value.
Per cent.	*Pounds.*	*Therms.*
2.5	0.041	0.19
3.0	.043	.21
3.5	.045	.24
4.0	.049	.27
4.5	.052	.29
5.0	.055	.32
5.5	.058	.34
6.0	.061	.36
6.5	.064	.39
7.0	.068	.41

REQUIREMENTS FOR WORK.

Since the horse (or mule) is the usual working animal in the United States, consideration will be limited to this animal.

There is on record a considerable amount of data as to the relation between the work performed by the horse and the amount of energy necessary to be supplied in the feed. Where large numbers of horses are kept and the work is relatively uniform in amount, it is possible to make fairly satisfactory computations from these data, although the method is somewhat complicated. The amount of work required of farm horses, however, is so varied in amount and kind and so difficult of measurement or estimate as regards amount, that it is scarcely practicable to base the calculation of rations upon it. The table on pages 11–13 probably shows with at least a fair degree of accuracy the relative values of different feeding stuffs as sources of energy for work production, while the amount to be fed will ordinarily be based upon the observation of the feeder rather than upon arithmetical calculations. As a sort of general average, however, Kellner recommends the following rations for a 1,000-pound horse, the amounts stated including the maintenance requirement:

Requirements of the working horse.

	Digestible protein.	Net energy value.
	Pounds.	*Therms.*
For light work	1.0	9.80
For medium work	1.4	12.40
For heavy work	2.0	16.00

DRY MATTER IN RATIONS.

The total volume of feed which an animal requires, although rather variable, has its limits. In computing rations the most convenient indication of the bulk of the feeds is the percentage of dry

matter shown in the first column of the table on pages 11–13. In very general terms it may be said that a 1,000-pound ruminant should be given from 20 to 30 pounds of dry matter per day, 25 pounds being perhaps a fair average, while for the horse smaller amounts will be appropriate.

A study of the table shows that concentrated feeding stuffs contain much more protein and energy in proportion to their dry matter than do the forage crops. Evidently, then, in heavy feeding, where the purpose is to give the animal all the feed possible, the ration should consist as largely as practicable of concentrated feeding stuffs, because only in that way can the required amount of nutriment be obtained without unduly increasing the bulk of the ration. On the other hand, in light feeding the coarse fodders may predominate, because they are usually relatively cheaper and can supply the required amount of nutriment in a bulk which the animal can consume.

THE COMPUTATION OF RATIONS.

GENERAL CONSIDERATIONS.

In the foregoing pages we have considered the requirements of the animal machine for repair material (protein), and for fuel material (energy), and have also studied the feed as a source of these two. If we knew exactly the requirements of the animal in any given case, and if we knew exactly what amounts of protein and energy the feeding stuffs at our disposal could furnish, the computation of a ration would be almost purely a matter of arithmetic. We would simply have to devise a mixture of the feeding stuffs which would yield the requisite amounts of protein and energy and would at the same time be of suitable bulk and of such a character as to exert no injurious action upon the animal.

As a matter of fact, we have no such exact knowledge. Practically, animals vary in their requirements, while feeding stuffs of the same name show a wide range in composition, digestibility, and nutritive value. Furthermore, what is still more important, the economic conditions vary from case to case so that, for example, a very liberal ration might be advisable in one instance, while for the same animal under different conditions it would be highly uneconomic. The figures given on previous pages can not be made the basis of infallible recipes which shall save the user the trouble of observing and thinking.

But notwithstanding all this, the foregoing data can afford valuable aid to the feeder. By their use he can get a general idea of the feed requirements of his animals and can compute a ration which will approximately supply the requisite amounts of protein and energy. His ability as a feeder will be shown, first, in his power

to estimate the conditions which will modify the feed requirements of his particular animals and cause his feeds to vary from the average, and, second, in the skill with which he can interpret the daily results and modify his feeding in accordance with them.

The problems given on the following pages are intended simply as illustrations of the method of using the tables and not as model rations. Limitations of space forbid the multiplication of examples, but the reader who grasps the method will have no serious difficulty in applying it to his own conditions, while facility will be acquired with surprising rapidity by practice. It will be observed that the form of these tables and the methods of computation do not differ materially from those which have been used for many years in computing rations on the basis of "digestible nutrients," although the significance of some of the figures is different. It may be added that the digestible protein in the tables is true protein—that is, it does not include the so-called "amids" of the "crude protein." Consequently the percentages, as well as the amounts estimated in the rations on succeeding pages, are somewhat smaller than in the older tables.

TOTAL FEED REQUIRED.

A bunch of "feeders" 2 to 3 years old, averaging 1,000 pounds per head and in better than average condition, are to be fattened on clover hay and corn-and-cob meal. Such cattle, if of good grade, should weigh 1,400 pounds each when ready for market and should not require over 200 days to make the gain of 400 pounds. They should therefore make an average gain of 2 pounds per day.

It may be estimated that a gain of 1 pound live weight by animals of this grade will require about 3.5 therms of net energy value in the feed; for a daily gain of 2 pounds, therefore, the requirement would be 7 therms. To this must be added the maintenance requirement, which will increase as the animals grow heavier. For the average weight of 1,200 pounds it is sufficiently accurate to use the maintenance requirement computed in the table on page 14 for 1,250 pounds, viz, 7 therms. This makes the total net energy requirement per day 14 therms on the average of the whole feeding period.

If we assume that 2 pounds of grain will be fed for each pound of hay, it is easy to compute from the figures in the last column of the table on pages 11–13 the amount of feed required to supply 14 therms of net energy, as follows:

	Therms.
In 100 pounds of average clover hay	38.68
In 200 pounds of corn-and-cob meal	151.60
In 300 pounds of feed	190.28
In 1 pound of feed	.634

To supply 14 therms requires $14 \div 0.634 = 22.08$ pounds of total feed, consisting of 7.36 pounds of clover hay and 14.72 pounds of corn-and-cob meal, or, in round numbers, 7½ pounds of hay and 15 pounds of meal.

This, of course, represents the average ration for the whole feeding period. At the begnning the feed will naturally be lighter and consist to a larger extent of hay, while the amount of feed, and especially the proportion of grain, will be gradually increased until toward the end of the feeding the animals are consuming all the grain they will take, with only enough hay to insure the necessary bulk and proper digestion. Naturally, too, the form in which the corn is given will usually be varied in the course of the feeding.

IMPROVEMENT OF A RATION.

In the foregoing example it was assumed that the feeding stuffs to be used had been decided upon and attention was directed simply to the quantity required. Let us now take up the question from the other end and see whether a study of the ration may not yield some suggestion of possible improvement.

According to the table on pages 11–13, clover hay and corn-and-cob meal, respectively, contain in 100 pounds—

Feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay	87.1	4.9	38.68
Corn-and-cob meal	89.6	5.7	75.80

The 7½ pounds of clover hay in the ration will evidently contain:

87.1 ×0.075=6.53 pounds of dry matter.
4.9 ×0.075=0.37 pound of digestible protein.
38.68×0.075=2.90 therms of net energy value.

A precisely similar computation for the corn-and-cob meal gives the following results:

89.6×0.15=13.44 pounds of dry matter.
5.7×0.15= 0.85 pound of digestible protein.
75.8×0.15=11.37 therms of net energy.

Adding these amounts, we find that the total ration contains:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay, 7½ pounds	6.53	0.37	2.90
Corn-and-cob meal, 15 pounds	13.44	.85	11.37
Total	19.97	1.22	14.27

The quantity of energy, of course, corresponds with that estimated to be necessary, because the amounts of feed were fixed upon on that basis. We observe, however, that the amount of digestible protein in the ration is less than is estimated on page 16 to be needed by beef cattle of this age. A ration like the above might produce fair gains, but it probably would fail to take full advantage of the capacity of such cattle for growth and the gain would most likely fall below that which was anticipated. An increase in the protein could be expected to make the ration more efficient.

To make any marked change in the ration in this respect, it is evident that we must introduce into it some feed much richer in protein than either of those composing it. On consulting the table it is evident that what we need is one of the by-product feeds like gluten feed or meal, the oil meals, etc., and also that only a small amount of one of these will be needed to effect a marked change in the ration. Thus, if we substitute 2 pounds of old-process linseed meal for 2 pounds of the corn-and-cob meal, the ration will foot up as follows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Clover hay, 7½ pounds	6.53	0.37	2.90
Corn-and-cob meal, 13 pounds	11.65	.74	9.85
Old-process linseed meal, 2 pounds	1.82	.57	1.78
Total	20.00	1.68	14.53

Thus at a comparatively small additional expense we are able to improve the ration materially by adding the lacking protein, and there is little doubt that the improved ration would produce a more rapid gain and, under ordinary conditions, a more profitable one as well, either by increasing the total gain or shortening the feeding period.

COMPUTING A RATION FROM GIVEN FEEDING STUFFS.

There are available for a dairy herd field-cured corn forage (including the ears), clover hay, corn meal, wheat bran, and gluten feed. The table on pages 11–13 shows that these feeding stuffs, if of good average quality, will furnish in 100 pounds:

Feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage	81.7	2.3	43.94
Clover hay	87.1	4.9	38.68
Corn meal	88.7	6.4	88.75
Wheat bran	89.9	10.8	53.00
Gluten meal	90.9	28.1	84.15

The cows average 850 pounds per head and have produced in previous years an average of 20 pounds of milk per day testing 4 per cent of fat. According to the table on page 14, the maintenance requirement of such animals per day and head would be approximately—

Digestible protein	pound..	0.43
Net energy	therms..	5.40

For the production of 20 pounds of 4 per cent milk there would be needed, according to the estimates on page 18:

Digestible protein (0.05×20)	pound..	1.0
Net energy (0.27×20)	therms..	5.4

The total feed requirements per day and head are therefore:

	Digestible protein.	Net energy value.
	Pounds.	*Therms.*
For maintenance	0.43	5.40
For milk production	1.00	5.40
Total	1.43	10.80

The problem, then, is to find a mixture of the available feeding stuffs which will yield these amounts of digestible protein and of energy, and which shall have a suitable bulk.

The first step in the construction of a ration is to fix upon the amounts of coarse fodders. It is usually desirable to use as large a proportion of these as possible, since they are usually cheaper sources of food than grain. On the other hand, the amount of them which an animal can consume is limited. Much depends upon the individual animals, and the proper amount can only be told by trial, but we should probably aim to get from 12 to 14 pounds of dry matter in the form of coarse fodder. Corn forage being a cheap feeding stuff, we shall naturally use this freely, with probably some hay for variety. By a little trial, we find that 10 pounds of corn forage and 6 pounds of clover hay will give us 13.4 pounds of dry matter and the amounts of digestible protein and of energy shown below:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 10 pounds	8.17	0.23	4.39
Clover hay, 6 pounds	5.23	.29	2.32
Total	13.40	.52	6.71

To this we have to add sufficient grain to bring the ration up to the requirement. The proper amount we must ascertain by trial. We will take, at a venture, 4 pounds of corn meal and 2 pounds of wheat bran. Adding this to the ration we have:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 10 pounds	8.17	0.23	4.39
Clover hay, 6 pounds	5.23	.29	2.32
Corn meal, 4 pounds	3.55	.26	3.55
Wheat bran, 2 pounds	1.80	.22	1.06
Total	18.75	1.00	11.32

Comparing these totals with the requirement as computed, we find that the ration is ample as regards energy but considerably low in digestible protein. The rather low figure for dry matter shows that more feed may be added to the ration if desirable, but the total for net energy makes it evident that what is needed is not more feed, but feed of a different composition, supplying more protein along with rather less energy. Gluten meal answers this requirement, and substituting 2 pounds of it for 2 pounds of corn meal gives a ration which, while still a trifle high in energy, agrees as closely as necessary with the computed requirements. Thus:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net-energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn forage, 10 pounds	8.17	0.23	4.39
Clover hay, 6 pounds	5.23	.29	2.32
Corn meal, 2 pounds	1.77	.13	1.78
Wheat bran, 2 pounds	1.80	.22	1.06
Gluten meal, 2 pounds	1.82	.56	1.68
Total	18.79	1.43	11.23

This ration corresponds with the average requirement of the whole herd, since it is based on its average performance. It hardly need be said that it should be modified to suit the requirements and capacities of the individual cows, the heavy milkers getting more and the lighter ones less.

By proceeding in this manner, with a little patience we can usually get a ration corresponding as closely as is necessary to the requirement, provided the feeds available admit of it. With a little experience one very soon learns to guess pretty closely, and with some practice the computations become very easy. An exact agreement with the requirement need not be sought for, since in practice the composition of the feeds will probably vary more or less from the average of the tables.

THE CHOICE OF FEEDING STUFFS.

When, as in the last example, feeding stuffs must be purchased in order to get the desired relation between the protein and the energy of the ration, it is evident that often a wide range of choice may be offered. In such a case the question at once arises which of the various feeds available is it most economical to purchase, it being evident of course, that this is not necessarily the one offered at the lowest price.

No simple method of determining this point is possible, because, as we have seen, the feed serves two entirely distinct purposes in the body. Sometimes the supply of protein is the specially important point, and in other cases what is needed is a supply of energy without special reference to whether its source be protein or nonnitrogenous material. Consequently, the relative values of two feeding stuffs may vary under different circumstances. Some writers have based their comparisons of the values of by-product feeds solely upon their content of protein, for the reason that such feeds are often bought especially to supply this ingredient, while the fats and especially the carbohydrates are usually produced in abundance upon the farm. They regard that purchased feeding stuff as the most economical which furnishes a pound of digestible protein at the lowest cost, ignoring any value in the other ingredients. It is obvious, however, that this is a one-sided view. The other ingredients have a value, and this is especially true in the case of a feeder who buys a considerable part of his grain supply and depends upon it as a source of energy as well as of protein. The method of comparison illustrated in the following pages is based primarily upon the cost per unit of energy because this is on the whole the most important function of the feed, but the method takes account also of the amount of protein present.

Let us suppose the following feeding stuffs are available to a dairyman at the prices named:

Prices of feeds per ton.

Oats (40 cents per bushel)	$25
Corn meal	25
Wheat bran	21
Wheat middlings (flour)	24
Dried brewers' grains	23
Gluten meal	27
Cottonseed meal (prime)	30
Old-process linseed meal	33

The supply of coarse feed on the farm is sufficient to furnish each animal per day 32 pounds of silage and 8 pounds of clover hay; the cows average 1,000 pounds each and may be expected to produce per day about 24 pounds of milk testing 4.5 per cent fat.

The first step is to compute, in precisely the same way as in the previous example, the estimated requirements of these cows per day as follows:

	Digestible protein.	Net-energy value.
	Pounds.	*Therms.*
For maintenance	0.50	6.00
For 24 pounds of milk:		
Protein 24×0.052	1.25	
Net energy 24×0.29		6.96
Total requirement	1.75	12.96

The amount of silage and clover hay available will furnish, according to the table on pages 11–13, the following amounts of dry matter, digestible protein, and net energy value:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pound.*	*Therms.*
Corn silage, 32 pounds	8.42	0.19	5.09
Clover hay, 8 pounds	6.97	.39	3.09
Total	15.39	.58	8.18

The question now is what feeding stuffs is it most economical to buy (or to refrain from selling if in stock) to complete the ration. The first step in deciding this question is to compare the various feeds as sources of energy and see which one furnishes a unit of net energy value at the lowest price. This computation gives the following results:

Kind of feed.	Cost of 100 pounds.	Energy value of 100 pounds.	Cost of 1 therm net energy value.
		Therms.	*Cents.*
Oats	$1.25	67.56	1.85
Corn meal	1.25	88.75	1.41
Wheat bran	1.05	53.00	1.98
Wheat middlings	1.20	75.02	1.60
Dried brewer's grains	1.15	53.38	2.15
Gluten meal	1.35	84.15	1.60
Cottonseed meal	1.50	90.00	1.67
Old-process linseed meal	1.65	88.91	1.86

Evidently, if it were simply a question of supplying energy to the animals, we should use corn meal, since that supplies a unit of energy at a much lower price than any of the other feeding stuffs. If it were thought desirable to add variety to the ration, wheat middlings would obviously be our next choice.

It is evident, however, without going through the labor of computation, that while corn meal and wheat middlings may be used in the ration, neither will supply enough protein if used exclusively. Of the available feeding stuffs which are rich in protein and which may therefore serve to balance the deficiency of this ingredient, gluten meal is relatively the cheapest, and cottonseed meal comes next. While the difference between the two is not great, we shall naturally try the cheaper one. It is not difficult to determine by a few trials that 2½ pounds of corn meal and 3½ pounds of gluten meal, in addition to the coarse fodder available, will give a ration corresponding very closely to the requirements, as the following table shows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn silage, 32 pounds	8.42	0.19	5.09
Clover hay, 8 pounds	6.97	.39	3.09
Corn meal, 2½ pounds	2.22	.16	2.22
Gluten feed, 3½ pounds	3.18	.98	2.95
Total	20.79	1.72	13.35

This ration shows as close an agreement with the computed protein requirement as could be desired, but contains a slight surplus of energy. The comparatively low figure for dry matter indicates that more coarse fodder might have been used had it been available, with the probable effect of cheapening the ration. As it is, we have used the feeds relatively lowest in price and apparently have a very economical ration.

Cottonseed meal, however, is nearly as cheap as a source of energy as gluten meal, while it contains considerably more protein. It seems worth while, therefore, to see whether it may not be possible to secure the necessary protein more cheaply by using a smaller amount of the former feed in place of the gluten meal. Three pounds of cottonseed meal will supply almost exactly the same amount of protein as 3½ pounds of gluten meal. Making this substitution, the ration stands as follows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	*Pounds.*	*Therms.*
Corn silage, 32 pounds	8.42	0.19	5.09
Clover hay, 8 pounds	6.97	.39	3.09
Corn meal, 2½ pounds	2.22	.16	2.22
Cottonseed meal, 3 pounds	2.77	.96	2.70
Total	20.38	1.70	13.10

This ration agrees with the computed requirements even better than the previous one, while a simple comparison shows that it is actually a trifle cheaper. The grain portion of the two rations costs as follows:

Feed in ration.	First ration.	Second ration.
	Cents.	*Cents.*
Corn meal	3.13	3.13
Gluten meal	4.73	
Cottonseed meal		4.20
Total	7.86	7.33

It thus appears that the ration made up with the somewhat more expensive cottonseed meal is actually the cheaper. The difference, to be sure, is small, yet for 30 cows fed for 200 days it would amount to $30. Such a difference is only likely to be found, however, when, as was assumed in this instance, some feed very high in protein can be had at a relatively cheap rate. In general, it may be said that when there are no very marked differences in the cost of a therm of energy value in the feeding stuffs constituting the bulk of the ration one of the various high-protein feeds which supplies energy at the lowest cost should ordinarily be used, although it is always wise to check up this point, as in the example just given.

THE COMPOUNDING OF RATIONS.

While in the foregoing examples an exact daily ration is computed, it would, of course, be utterly impracticable in most cases to weigh out separately each day's ration for each animal. Individual weighings of feeds at intervals would often yield valuable information and might be profitably undertaken, but for the ordinary routine of feeding simpler methods must be used.

When practicable, the grain feed may be advantageously mixed in advance in the desired proportions in as large quantities as the storage capacity available and the proper preservation of the materials will permit. Where facilities are available, the whole amount of grain required for all the animals may be weighed out daily, or even for each feeding, without much additional labor. In distributing the grain to the individual animals, regard of course should be paid to their productive capacity and their individual peculiarities. The ration, as computed, is for the average animal. The skill of the feeder is shown in adapting it in quality and in amount to the individual. Doubtless individual weighings at intervals, as already suggested, would be useful as a control on the accuracy of the distribution.

The weighing of coarse fodder is usually a more difficult problem on account of its bulk. When, however, silage or cut fodder is handled in trucks, the matter is still comparatively simple. Long fodder, on the contrary, is not readily weighed. Nevertheless, even here an occasional weighing, if practicable, as a control upon the feeding, is very desirable.

In all these and similar matters common sense is necessary. The computed ration expresses the best estimate that can be made of the actual average requirements, but it is at best more or less of an approximation. It would be foolish, therefore, to seek extreme exactness in realizing it or to go to more expense in the weighing and apportioning of the feed than the saving in the latter would amount to. The scale upon which the feeding is conducted will play an important part. Where scores or hundreds of animals are being fed, an exactness may be profitably sought which would be absurd in the case of two or three animals. Finally, it should be remembered that these computed rations are guides and not recipes. They may aid the feeder in wisely using the resources at his command, but they can not take the place of experience and good judgment.

BEARING ON FARM MANAGEMENT.

The data and the methods of computation on previous pages will aid the feeder in determining the amounts of each class of feeds needed for each class of his animals. The man of good business habits will find them useful in determining the quantities of each kind of feed to grow or purchase and in deciding upon the purchase of animals to feed and the feeds to keep or to purchase for feeding them. These facts and methods will aid the farmer, the feeder, or the user of work animals in deciding upon the chances of profit in proposed enterprises. Often by using these formal ways of checking up a proposed business project the way is made more clear to avoid loss and to secure the largest practicable profit. In case of the farmer who grows most of his feed stuffs, these facts and methods of calculation may often be used in connection with the planning of his scheme of crop rotation and in proportioning the acreages of the respective crops to each other and to the numbers of each class of animals. They will prove useful in reducing the farm-management plan to a scientific basis.

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